Zooplankton Aggregation Near Sills

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LONG-TERM GOALS

Improved knowledge of the physical and biological mechanisms and interactions responsible for forming and maintaining aggregations of biological sound-scatterers in the ocean.

OBJECTIVES

Dense aggregations of plankton and fish often occur in localized regions where ocean currents interact with steeply-sloping bottom topography. These aggregation sites are ecologically important 'hot spots' for prey-predator trophic interactions, and are also zones of very strong acoustic backscatter. Our project will examine the biological and physical oceanographic mechanisms responsible for forming, maintaining and dispersing these aggregations near a 'model' bathymetric feature: the sill of Knight Inlet, a large fjord on the mainland coast of British Columbia (sill at 50º41'N 126º00'W).

APPROACH

We are combining new field measurements (years 2 and 3 = Oct 2001-Sept 2004) with retrospective analyses of previously collected acoustic and physical oceanographic data (mostly completed in year 1 = Jan-Sept 2001). In both cases, our approach is multidisciplinary, linking the well-resolved spatial distributions provided by the acoustic data with the interpretive capability provided by the *in situ* physical and biological measurements. Sampling tools include: multi-frequency acoustics to measure cross-sill vertical sections of the back-scatter intensity and horizontal velocity (drift + swimming); an instrumented multiple plankton net (BIONESS) and an optical plankton counter (OPC) for zooplankton abundance, species composition, and body size/shape; a high resolution digital camera for zooplankton body/swimming orientation; CTD and transmissometer to describe temperature, salintiy, and turbidity fields; and moored acoustic doppler current meter (ADCP) and echo-sounders for tide-resolving time series of current velocity and back-scatter intensity near the sill.

Choice of study site is another important element of our approach. Aggregations of sound scatterers have been observed associated with a variety of bathymetric 'edges', including continental shelf break and slope regions (e.g. Simard and Mackas 1989; Mackas et al. 1997; Swartzman et al. 1999) and the margins of shelf banks and basins (Coyle et al. 1992; Haury, Briscoe and Orr 1979), submarine canyons (Allen et al. 2001, Greene et al 1988, Mackas et al. 1997), seamounts, and the edges, sills and headwalls of steep-sided inlets (Simard et al. 1986, Simard and Lavoie 1999, Romaine et al. in press). However, most of the above settings are hydrodynamically complex. To aid observation and understanding of interactions between flow field, bathymetry, and biology, we have selected as our study site the region surrounding the Knight Inlet fjord sill. This site provides (at least by oceanic standards) a very well-defined observational environment: strong cross-isobath flow that is predictably time-varying at semidiurnal, diurnal and fortnightly time scales, weak along isobath flow, clearly identifiable upstream and downstream locations and populations. There is also a wealth of previously collected acoustic and physical oceanographic information from previous research programs (e.g. Farmer and Armi 1999)

Expertise and project responsibilities of the lead investigators have been as follows.

- D. Mackas is a biological oceanographer and zooplankton ecologist with expertise on zooplankton spatial pattern. He is responsible for scheduling and overall coordination of field surveys (Nov 2001 and Nov 2002), net tow sampling of zooplankton, CTD sections, and the ADCP mooring. He also assists with the multi-frequency acoustic surveys.

- M. Trevorrow is an acoustician and physical oceanographer. He is responsible for retrospective analysis of older acoustic transects, and for acoustic measurements on the new field surveys.

- M. Benfield is a biological oceanographer and zooplankton ecologist with expertise on optical imaging methodologies. He is responsible for measurements with the high resolution digital camera, and assists with collection and interpretation of other zooplankton data.

- D. Farmer is a physical oceanographer and applied acoustician. He has provided interpretation of Knight Inlet physical oceanography, and access to data from prior surveys.

Additional participants in the project (but not funded by ONR) include:

- D. Yelland (Institute of Ocean Sciences): oceanographic field support and processing of acoustic and CTD data.

- D. Tuele (Institute of Ocean Sciences): oceanographic field support, mooring deployments.

- M. Tsurumi (NSERC post-doctoral fellow, Institute of Ocean Sciences and University of British Columbia): biological oceanographer, working on ecological interpretation of aggregation dynamics

- R. Campbell (PhD. student, University of Victoria): collection and analysis of OPC profiles

- T. Ross (PhD. student, University of Victoria): partitioning of acoustic back-scatter between plankton, fish, and turbulent microstructure

WORK COMPLETED

Year 1 (Jan-Sept 2001)

This was a start-up phase consisting of four activities (results reported in greater detail last year's annual report):

1) Retrospective analyses of acoustic data from earlier surveys of Knight Inlet (Trevorrow, award #N00014-01-1-0273).

2) Acquisition and testing a new three-frequency downward-looking echosounder (40 KHz, 100 KHz, 200 KHz) based on a separate system previously developed by the Farmer lab. We also added an Optical Plankton Counter (Focal Technologies OPC) to our BIONESS multiple net sampler.

3) Planning and booking of ship time for the first of the new field surveys

4) Benfield (under separate funding) continued development of his digital camera system.

Year 2 (Oct 2001-Sept 2002)

The major project activity was staging, execution, and analysis of data from the year 2 field survey (CCGS VECTOR 12-26 November 2001), and development of plans for the year 3 field work. Under the Mackas component (ONR award #N00014-01-1-0274), ONR funding covered 50% of ship costs, pre- and post-cruise upgrading of BIONESS and ship-mounted and moored acoustic sensors, and collection and processing of zooplankton net tow samples (62), along inlet CTD section (16 stations), and ADCP data (1 week deployment). We also provided the net-tow, OPC, and CTD profiles used by Trevorrow and Ross to calibrate and interpret the output of the multi-frequency echosounders.

Planning of the second (year 3) field survey is mostly completed. We will again have a 2 week cruise aboard CCGS VECTOR (11-25 November 2002). An important addition to the program will be use of a small otter trawl to sample fish aggregations, which occur at the upstream crest of the sill, and we believe exert heavy predation pressure on the nearby zooplankton aggregations as they are advected toward and over the sill (see Results).

RESULTS

1. Physical setting

The outer part of Knight Inlet is a fairly straight, uniform-width channel that runs approximately east-west. In the middle of this, near a point of land called Hoeya Head, there is a sill (approximately north-south) with sill depth near 60 m. The profile over the sill is asymmetric, with the western side steeper than the eastern side, and the crest of the sill is nearly flat. On the western side the sill falls away to about 150 m, while on the eastern side the depth reaches more than 400 m. The inlet has mostly semi-diurnal tides (strong fortnightly modulation), with tidal range from 1 to 4.5 m. The flood tide runs eastward. The head of the inlet receives melt-water from several ice fields. This strongly affects both salinity and turbidity fields throughout the year, although the annual surface layer turbidity maximum is in summer during the runoff peak. Surface layer turbidity reduces water column light penetration and results in a relatively shallow daytime zooplankton scattering layer (50-85 m, vs. ~100-150 m in nearby oceanic waters). At the time of our survey, the annual autumn-winter cooling of the surface layer was already underway.. Figure 1 shows along inlet sections of temperature, salinity and turbidity from our Nov 2001 survey.

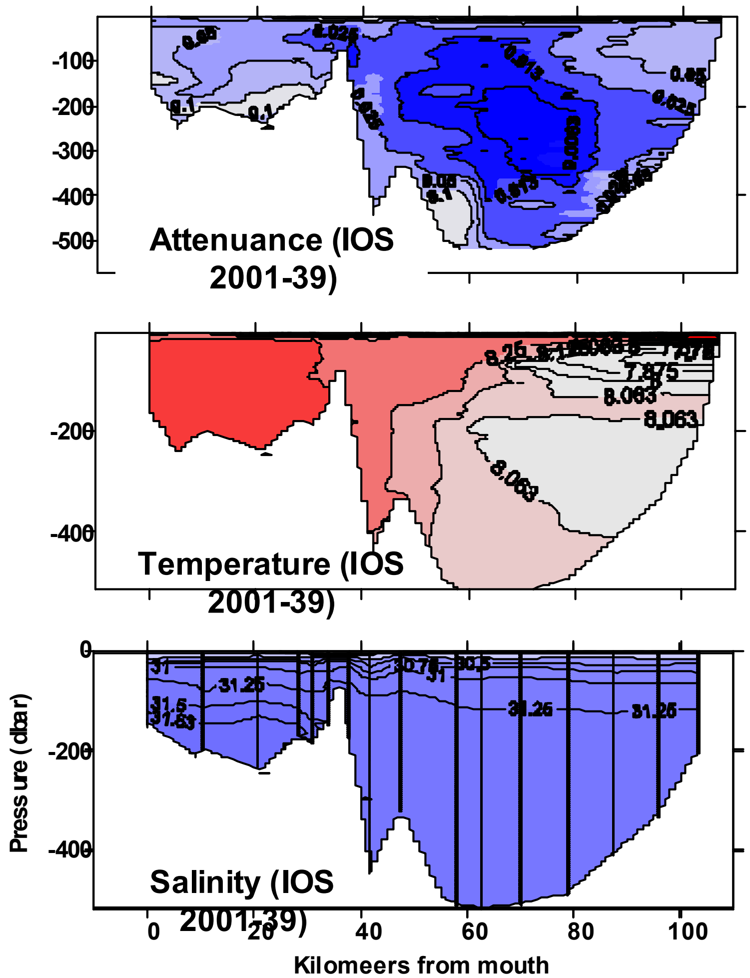

Figure 1: Knight Inlet axial sections of beam-attenuance, temperature and salinity. The mouth (west) end of the inlet is at the left, the head of the inlet (northeast) is at the right, the sill is between km 35-36. Note the enhanced vertical mixing caused by strong tidal currents across the sill.

2. Broad-scale distribution of euphausiids in Knight Inlet

Euphausiids were the dominant contributor to macrozooplankton/micronekton acoustic backscatter. During our survey, both net tow catches and acoustic back-scatter profiles showed a very intense, but very localized, euphausiid maximum in the immediate vicinity of the sill. This abundance maximum was located at 60-80m depth, and was consistently found on whichever side of the sill was the (tidal) upstream (i.e. aggregations would form and dissipate on each side of the sill on alternating phases of the flood-ebb cycle). See Trevorrow report (ONR award # N00014-01-1-0273) for additional discussion.

The localized near-sill zooplankton maximum (typically 1-2 km along inlet dimension) was embedded in a larger-scale broad minimum (Figure 2). Concentrations at locations ~2-10 km from the sill averaged about an order of magnitude lower than those within the sill-margin maximum, and about a factor of 2-3 lower than at locations 20-30 km from the sill.

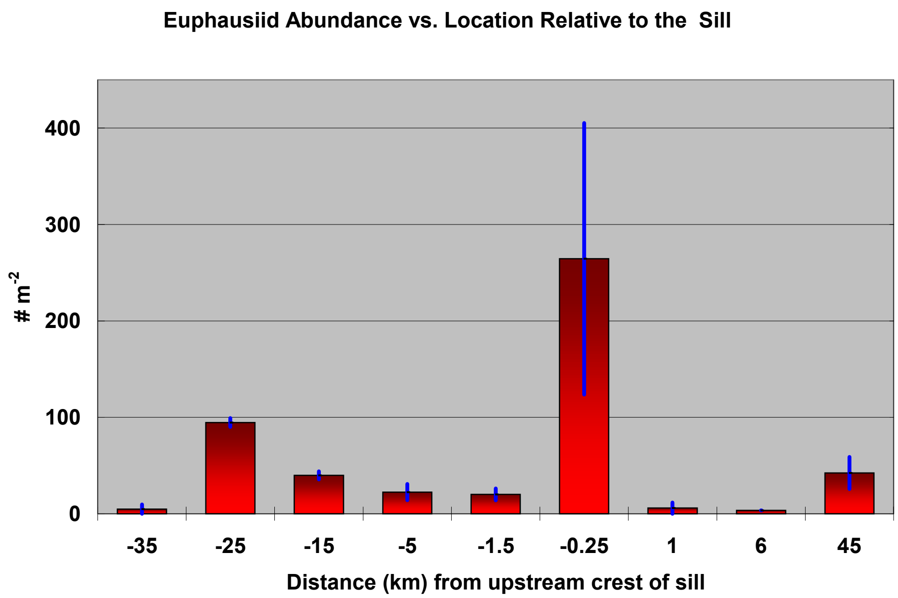

Figure 2. Summary plot of euphausiid abundance in Knight Inlet net tow samples vs. distance from the upstream crest of the sill (vertically-integrated summary of all net tows, BIONESS and bongo). Bars are average abundance within a distance class. Lines show standard error within distance class. This general pattern was repeated/confirmed by a large number of acoustic transects.

3. Interactions Between Zooplankton and Predator Aggregations

We now suspect that a cause of the broader scale minimum in euphausiid abundance is intense predation at the sill by planktivorous finfish. The sill provides an excellent foraging site for visual predators because each tidal cycle is accompanied by a daytime midwater aggregation of euphausiids that is advected against the upstream face of the sill. Expected along inlet displacements are 3-6 km per flood or ebb (varying with phase in the spring-neap cycle).

Because we had a three frequency echosounder system (50kHz, 100kHz and 200 kHz), we were able to make some acoustic discrimination among targets based on differences in body size. We regularly observed dense daytime aggregations of larger acoustic targets located at the crest of the sill (see Fig. 3 on the following page). We do not yet have confirmation of what these targets were, but during night periods we visually observed at the sea surface very high abundances of small fish (approx. 10 cm body length, probably juvenile herring and/or salmonid smolts).

Location of the 'fish' aggregations shifted from inshore to offshore side of the sill with tidal phase, but appeared to anticipate the change in tidal current direction. For example, the tidal flow was ebbing (current direction from left to right) in the four upper panels Fig 3, but the 'fish' began to move to the west (right hand) side of the sill during mid-late ebb. By the start of the flood tide, most were located at the west rim of the sill, in place for the approaching and strengthening west slope krill aggregation (bottom two panels)

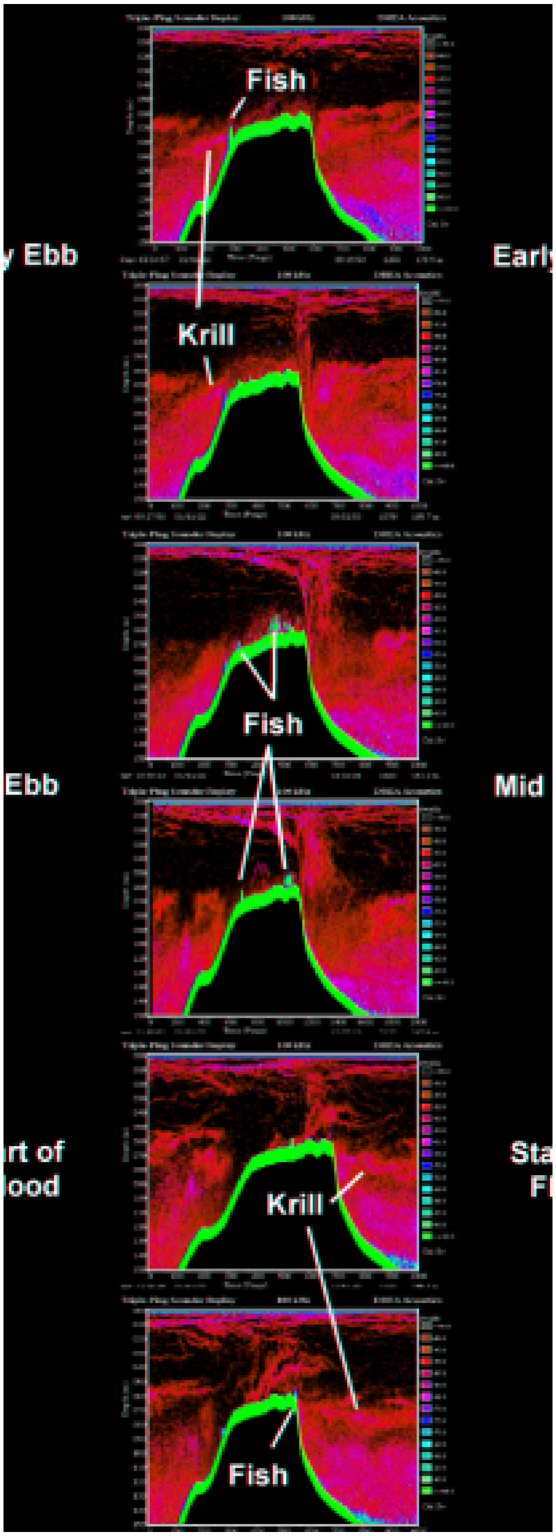

Figure 3. Part of a 22 November time series of ten repeated acoustic transects across the Knight Inlet sill. Horizontal scale is 5 km. East is at the left of each panel. Arrows in the right hand margin indicate tidal current direction and speed. Epibenthic 'fish' aggregations and midwater krill aggregations are indicated by labels and white lines.

We were very intrigued by the interaction of prey and predator distributions and aggregation strategies. We plan to examine this in greater detail in the upcoming 2002 field work. Specifically, we will use a small otter trawl to fish along the sill crest. At minimum, this will give us target identifications. We hope it will also give us some information about predation rate and selectivity.

4. Discrimination between turbulent microstructure and biological scatterers

Our surveys (and earlier work in Knight Inlet by Farmer, Armi, Dewey, Lueck and others) also show instances of strong acoustic backscatter in the near-surface (upper 10-20 m) layer. Far from the sill, the depth of this layer corresponds to the interface between low salinity surface, and more saline deep estuarine layers. On the tidal downstream side of the sill, an internal hydraulic jump can produce a downward deformation to sill depth or below (see e.g. panels 3 and 4 of Fig. 3). Trevorrow is working with T. Ross and C. Garrett (University of Victoria) to learn how much of the back scatter from this layer is from physical microstructure, and how much from advected 'biological' targets. Initial results suggest that the upper scattering layer is primarily 'physical' in origin - net tows collected essentially no macrozooplankton, and ambient densities of the smaller mesozooplankton.

IMPACT/APPLICATIONS

Results of the retrospective analysis have been published as a DREA Data Report (Trevorrow 2001). An initial interpretation of our 2001 results will soon be presented at major international conference (the October 2002 PICES/GLOBEC conference in Qindao, China, Trevorrow et al. 2002). We will combine these with additional results from the upcoming Nov 2002 field survey to test hypotheses about zooplankton aggregation and transport mechanisms, predator strategies, and acoustic back scatter models. Once established for a relatively simplified flow regime, these can then be applied broadly to other regions with more complex flow patterns

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